DEPOSITION 2001: SOFTWARE FOR CALCULATING PERFORMANCE OF AEROSOL SAMPLING SYSTEMS

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ABSTRACT

The DEPOSITION code is acceptable methodology for estimating aerosol particle transport through sampling systems by the NRC, by ANSI N13.1-1999 and by EPA for DOE facilities. A new version of the code is being developed and should be available for release by November 1, 2000. The code allows calculation of aerosol transport efficiencies of sampling systems that contain one or more of the following components: inlet nozzle, straight tube, bend, contraction, expansion and flow splitter. In comparison with previous versions of the code, this release is more user-friendly from the point of view of data input and output, and new models have been used for prediction of aerosol penetration through bends and splitters. Herein, an example of the use of Deposition 2001 is given, and for quality assurance purposes, results are shown that compare hand calculations and code predictions for aerosol penetration through each of the individual components.

INTRODUCTION

The United States law (40CFR60, Subparts H and I) requires continuous emission monitoring of stacks and ducts at U.S. Federal facilities that can potentially release significant quantities of radionuclides to the environment. The criterion to determine whether a stack must be continuously monitored is based on the dose that can potentially be acquired by the most effected off-site individual. The maximum dose is 10 mrem in a year, and any emission point that can potentially cause more than 1% of the limit must be monitored. Meteorological modeling is used to calculate dose, and source term used in the meteorological modeling is based on the form of releasable radionuclides (solid, powder, liquid, vapor) and the assumption that air pollution control equipment is ineffective. The latter assumption is equivalent to an accidental release of the radionuclides. The U.S. Environmental Protection Agency is empowered to assure that facilities are in compliance with these requirements.

For stacks and ducts that must be continuously monitored, the present US law states that the sampling of emissions, when extractive sampling is used, shall be performed in accordance with the guidance of an American National Standards Institute standard, ANSI N13.1-1969. Although the goal of this standard was to obtain representative samples of the radionuclide emissions, the goal was not achieved. As the name suggests, the standard was adopted by ANSI in 1969, and during the past 30 years it has been shown to be inadequate by numerous studies and technological advances. These deficiencies include:

- *Poor sampling characteristics for supramicrometer-sized aerosol particles.* Under the assumption that control equipment is rendered inoperative, the aerosol size distribution emitted by a stack or duct is that associated with normal conditions upstream of the control equipment. Typically these sizes are in the range of 1 to 10 μm aerodynamic diameter (AD), depending upon the type of operation that causes radionuclides to be aerosolized.

  ANSI-1969 prescribes sharp-edged isokinetic nozzles for extraction of aerosol samples from the gas flow in the stack or duct. For larger-sized ducts, multiple nozzles mounted on rakes are generally used in an attempt to obtain spatially representative samples. However, the loss of aerosol particles in these probes is large – Fan et al. (1992) tested a nozzle from an ANSI-1969 compliant rake and found that 75% of 10 μm were inadvertently deposited on the inner wall of the nozzle. ANSI-1969 has also been used for the design of extractive sampling systems by licensees of the US Nuclear Regulatory Commission. As an example, the typical tubing used to transport extractive samples from the stack of a nuclear power reactor to the collection location is 52 m (170 feet) in length and is 6 mm (1/4 inch) diameter tubing. While such a system may be compliant with ANSI-1969 requirements, aerosol particles would not penetrate the tubing and reactive gases (e.g., iodine) would not penetrate it in a manner that would either provide an adequate basis for a timely alarm or for assessment of the magnitude of the release.

- *Standard is design based rather than performance based.* Details are given on the design of nozzles and rakes; however, there are no requirements placed on performance. For example, a probe could have an inlet through which a pin could not pass, and, provided it were operated isokinetically, its use could be acceptable even if virtually no 10 μm AD aerosol particles would penetrate.

- *There are no maintenance requirements.* Apparatus, once installed does not need to be checked for assurance that it performs satisfactorily. For example, the U.S. DOE Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM is designed for storage of low level wastes in rooms in a layer of bedded salt. When mining of the salt is taking place, there is considerable dust in the exhaust ventilation air. When WIPP was being mined in the 1980's, an ANSI-1999 compliant sampling system, which used two rakes of isokinetic nozzles, was installed and operated to establish base-line conditions for air quality before the arrival of nuclear waste. After a short period it was noticed that the nozzles were plugged with salt. Under ANSI-1969, there was no requirement to check for such deposits. WIPP; however, replaced the sampling system with a more robust system that utilized large-diameter shrouded probes (McFarland et al., 1989) and large diameter sampling lines.

- *Incompatible with even itself.* The 1969 version of ANSI N13.1 is based on the concept of representative sampling; however, the design of the sample transport lines assures that the aerosol samples will be non-representative. In addition, the design recommended for rakes of isokinetic nozzles that span across the stack also assures that the sampling will be anisokinetic. The flow through a sampling nozzle (and velocity at the inlet plane) is controlled by the suction applied to the sampling manifold, so the velocity in all nozzles of a rake will be approximately the same. However, the velocity profile across a stack is not uniform and so the condition of isokineticity cannot, in general, be achieved for all nozzles.

The problems with ANSI-1969 were documented by McFarland and Rodgers (1993) who suggested the ANSI-1969 approach should be replaced by new methodology; namely single point representative sampling. The basic concept is that a representative sample can be extracted from a location where contaminant concentration (aerosol or vaporous radionuclides) and fluid momentum are both well distributed as evidenced by the uniformity of concentration and velocity profiles. This concept was approved by the U.S. Environmental Protection Agency for use at DOE facilities (US EPA, 1994) subject to the requirements:

- The coefficients of variation (*COVs*) of velocity and test tracers (gas and aerosol particles) must be ≤ 20% over the central 2/3 of the area of an EPA Method 1 (US EPA, 2000) grid. At no point on an entire grid should the concentration of tracer gas be more than 30% higher than the mean concentration. A *COV* is the ratio of the standard deviation of a set of measurements to the mean value of the measurements.
- A shrouded nozzle (McFarland et al., 1989), which is used to extract the sample from the stack or duct, must meet well defined performance criteria.
- The sampling system must allow at least 50% of the 10 μm AD aerosol particles to be transported from the free stream in the stack or duct to the collector or analyzer. The computer software, DEPOSITION 2.0 or higher must be used to verify the performance of the sampling system.

The submodels used in Deposition (Depo) were first programmed under funding from WIPP, where the software was used to provide a means for optimizing the performance of sampling systems. Later, the models enhanced, expanded and consolidated into a code that was made generally available under funding from the U.S. Nuclear Regulatory Commission (e.g., Riehl et al., 1996). The NRC adopted the code as suitable methodology for evaluating losses of aerosol particles in sampling systems (US NRC, 1992). The version of the code presented herein is a further upgrade that provides improved sub-models for predicting the performance of various components of the sampling system, and offers better input and output capabilities.

The standard ANSI N13.1 was revised in 1999 (ANSI, 1999) and the concept of single point representative sampling is embedded in it. Proper mixing must be demonstrated for a sampling location to be suitable, and either scale model laboratory tests, field tests, or documentation from tests on a similar emission point can be used to qualify the sampling location. For extractive sampling, acceptable apparatus must allow at least 50% of the sample to penetrate from the free stream in the stack or duct to the location of the collector or analyzer. If aerosol particles can be present in the stack or duct, the default particle size is 10 μm AD. Deposition software is an acceptable method of demonstrating that a sampling system meets the criterion.

EXAMPLE OF USE OF DEPOSITION 2001

When DEPOSITION 2001 has been started, the first screen appears as shown in Figure 1. To open the application, click on the drop-down "File" menu item on the toolbar and select either "New" to start a new analysis or "Open" to access a previously stored analysis. If you select "New," a dialog box will open that will allow you to either create your own setup or to use a Setup Wizard that will lead you through the process. The dialog box will also give you the additional option of opening a previously stored file. For the present example, we will select "New."

Design and Operational Parameters.
Suppose it is desired to calculate the total penetration for a transport system with the following operational and design parameters:

- Sampled air temperature of 29.3°Celsius.
- Sampled air pressure of 760 mm Hg.
- Particle density of 1 g/mL.
- Flow rate of 60.0 L/min.
- Transport tube diameter of 30 mm.
- Free stream velocity in the stack or duct of 12.5 m/s.

Assume the transport system consists of the following elements:

- A commercially available shrouded probe: Model RF-2-111.
- A horizontal tube of 0.5 m length.
- A 90° bend that changes the flow direction from horizontal to vertical (with airflow in the clockwise direction from entrance to exit). The specification of direction is used in a pictorial representation of the sampling system, but plays no role in calculations.
- A vertical tube 1.5 m long with the inlet above the outlet (the relationship of inlet and outlet needs to be specified; however, the direction of flow is only used in constructing the pictorial representation of the system).

Because the ANSI-1999 standard uses a 10 μm AD aerosol particle size for testing system performance, let us assume a monodisperse distribution with that size. In this case we will input a size of and, because we have chosen a particle density of 1 g/mL, the 10 μm is the aerodynamic diameter.

Input of System Properties and Parameters.
To start the analysis, first open the "Setup" drop-down menu on the toolbar. Then select the "System Properties and Parameters" option, which will open the dialog box shown in Figure 2. When the dialog box first appears, default values are shown; however, the values given in Figure 2 have been changed to represent those for the present example. To change any value, use the mouse to highlight the entry, then type in the revised value. When the entry process is complete, the "OK" button should be selected using the mouse.

Input of System Geometry.
The geometry of the transport system is configured by selecting the "Transport System" option in the "Setup" menu, which opens the dialog box shown in Figure 3. The dialog box shows the elements of the default transport system. The first element we consider is a probe, so we double-click on Element No. 1 in the dialog box, which opens an "Element Number" dialog. By selecting "Probe," the program provides a list of several probe options (Figure 4). Here, we select "Commercial" probes, and the program provides a list of commercially-available shrouded probes. We then select "RF-2-111" for the shrouded probe, and click "OK," which returns us to the "Transport System" dialog box.

We then double-click on "Element No. 2," which again opens the "Element Number" dialog box. Note that this box is different than the "Element No. 1" dialog box in that a probe is no longer an option among the different element types. "Cancel" can be used to return to the "Transport System" dialog box.
The second element in the example transport system (a 0.5 m long straight horizontal tube) differs from the default element, which was a bend. Selecting the "Tube" option and clicking "OK" provides the dialog box shown in Figure 5. We now proceed with setting up this element as per the specification of the example. The rest of the elements are added in the same manner, and the options

available in each element type are self-explanatory. The "Rotation" information, in the Bend Element dialog box, is simply for orientation purposes in the pictorial display of the transport system (which will be addressed later).

The fourth and final element is a tube with flow directed downwards in the vertical direction. We enter the angle as 90° from the horizontal, and the tube length (1.5 m), and click "OK," which returns us to the "Transport System" dialog. Clicking "Done" on that dialog completes the process if generating the geometry of the transport system.

Input of Particle Size Data.
The final item to set up is the particle size distribution. Selecting the "Particle Size Distribution" option from the "Setup" menu, opens the "Particle Size Distribution" dialog box. Figure 6 shows the "Particle Size Distribution" dialog, and the three possible choices for a particle size distribution. The particle size distribution for our example is monodisperse with a 10 μm diameter so "Monodisperse" should be selected along with the value of "10," which are the default settings, and then clicking "OK." There exist other options for polydisperse aerosols with log normal or user-defined distributions. Once all system properties, transport system and particle distribution parameters have been set, the analysis may begin.

ANALYSIS

To have the program perform the desired calculations, the "Analysis" menu is opened. For the sample calculation, an analysis of total penetration is needed, and therefore that option is selected from the drop-down "Analysis" menu. Deposition 2001, now calculates the total penetration, and reports this value along with the values of Stokes number and Reynolds number. The program is configured to report any discrepancies in the analysis. For example, if the user specifies a Reynolds number that is out of the range of applicability of the appropriate sub-model, this discrepancy will be reported. Although a value for penetration is reported even if the input values are out-of-range, the user must check the parameters entered. Cases outside of a range involve extrapolation, and hence the value of penetration reported may not be not reliable. In such a case, user discretion is advised in analysis of the values reported.

General characteristics appearing in the penetration report are shown in Figure 7. The screen in the report window can be printed using the "Print" option in the "File" menu.

Selection of the "Penetration with Varied Parameters" option under the "Analysis" menu opens a dialog box. The dialog allows variation of one of three parameters: tube diameter (not valid for transport systems with contractions and/or expansions), flow rate, or particle diameter. Entry fields allow inputs of the starting value of a parameter, the ending value of the parameter, or the number of discrete intervals at which the calculations are to be performed. The report displayed in the child window shows the maximum penetration attained and the value of the parameter at that optimum penetration, any problems encountered during the analysis, and a graphic plot of penetration versus the varied parameter.

VIEW DIALOGS

Other information besides analysis of results may be viewed, and specific parameters may be viewed using the "View" dialogs. The "View" dialogs may be toggled open or closed using the "View" menu option. Each option will either open or close a view dialog for the set of data listed (which correspond to parameters accessed in the "Setup" menu).

To open the "View" dialog for the transport system, select the corresponding option in the drop-down menu of the toolbar. A dialog similar to that shown in Figure 8 should open. Unlike other dialogs, other program options may be selected or used concurrently with an open "View" dialog. Note the contents of the transport system are listed. Changes in transport system properties must be done through the "Setup" menu.

A three dimensional picture of the transport may be displayed in the report window by clicking the "View System" button in the "View" dialog. The system can be viewed in various angles, by rotating clockwise or counterclockwise about any coordinate axis. Figure 9 shows the drawing corresponding to the transport system used in the example (with the 90° bend and vertical tube).

By clicking the "Graph" button on the "View" dialog box, a frequency histogram for the particle size distribution will be shown. Usually the mass size distribution parameters, rather than number size, would be input to the program, so the histogram would be the mass fraction vs. particle size.

SAVING SETUPS AND RESULTS

The "File" menu allows the input parameters of the current setup to be saved and reloaded. A sampling system configuration (the combination of the geometrical layout of the transport system and the operational conditions including the particle size distribution) that differs from the default can be stored and retrieved later, thus both saving time otherwise spent re-entering the setup and providing an electronic record of the inputs.

The files are stored in *.mdb format and can be retrieved and displayed through use of Microsoft Access. An example of a dialog box in Microsoft Access if shown in Figure 10. Selection of one of the options (Analysis, Particle, etc.) will display the results in data base format. These results can be transported to other programs as desired.

COMPARISON OF RESULTS FROM USE OF SOFTWARE AND HAND CALCULATIONS

One of the quality assurance steps taken to verify the veracity of the code was to perform independent hand calculations using the sub-models that are embedded in the program, and then repeat the calculations using the software. The results, shown in Table 1, indicate that the models are properly programmed into the code.

ACKNOWLEDGMENTS

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REFERENCES

American National Standards Institute. (1999). *Sampling of Airborne Radioactive Substances from the Ducts and Stacks of Nuclear Facilities.* ANSI/HPS Standard N13.1-1999. Health Physics Society, 1313 Dolley Madison Ave., McLean, VA 22101.

Fan, B.J.; Wong, F.S.; Ortiz, C.A.; Anand, N.K.; McFarland, A.R. (1992). Aerosol particle losses in sampling systems. *Proc. 22nd DOE/NRC Air Cleaning Conference.* NUREG/CP-1030, CONF9020833.

McFarland, A.R.; Ortiz, C.A.; Moore, M.E.; DeOtte, R.E., Jr.; Somasundaram, S. (1989). A shrouded aerosol sampling probe. *Environ. Sci. Technol.* 23:1487-1492.

McFarland, A.R.; Rodgers, J.C. *Single Point Representative Sampling.* (1993). LA-12612-MS. Los Alamos National Laboratory, Los Alamos, NM.

U.S. Environmental Protection Agency. (1994). Letter from Mary D. Nichols, Assistant Administrator for Air and Radiation, US Environmental Protection Agency, Washington, DC to Raymond F. Pelletier, Director, Office of Environmental Guidance, US Department of Energy, Washington, DC. Dated November 24, 1994.

U.S. Environmental Protection Agency. (2000). *Method 1 – Sample and velocity traverses for stationary sources.* 40CFR61, Appendix A. Code of Federal Regulations, U.S. Government Printing Office, Washington, DC.

U.S. Nuclear Regulatory Commission. (1992). *Air sampling in the workplace.* NUREG-1400. US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC.

Table 1: Verification of the Depo Code. A comparison of results from hand calculations and use of code for determining penetration through various sampling system components.

Element	Type of Flow	Parameters	Penetration, %, Manual	Penetration, % Depo 2001
Tube	Turbulent	Dia = 25.4 mm; L = 2 m; Flow rate = 100 L/min	76.4	76
Bend	Turbulent	Dia = 25.4 m; Bend angle = 60°; Flow rate = 100 L/min; Curvature ratio = 4.0	95.5	95.5
Unshrouded isokinetic probe	Turbulent	Dia = 25.4 mm; Flow rate = 100 L/min.	92.2	92.3
Shrouded probe	Turbulent	Tube dia = 25.4 mm; Probe dia = 18.2 mm; Shroud dia = 40.0 mm; Flow rate = 100 L/min	85.5	85.5
Contractions	Turbulent	Tube dia = 25.4 mm; Outlet dia = 22.86 mm; Flow rate = 100 L/min; Half angle = 45°	99.8	99.8
Expansions	Turbulent	Tube dia = 25.4 mm. Outlet Dia = 30.0 mm. Flow Rate = 100 L/min. Half Angle = 45 deg	98.4	98.4
Commercial probe (RF2-111)	Turbulent	Tube dia = 25.4 mm; Flow rate = 100 L/min.	92.1	92.1
Commercial probe (RF2-112)	Turbulent	Tube dia = 25.4 mm; Flow rate = 100 L/min.	118	118
Commercial probe (RF2-113)	Turbulent	Tube dia = 25.4 mm; Flow rate = 100 L/min.	121	121
Splitter	Turbulent	Inlet dia. = 25.4 mm; Outlet dia. = 17.78 mm; Angle = 30°; Flow rate = 100 L/min.	96.6	96.6

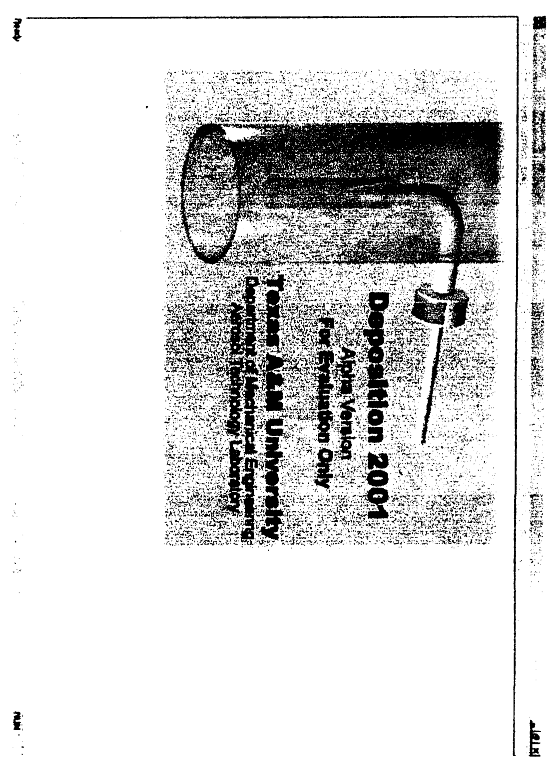

Figure 1: The Opening Screen of Deposition 2001.

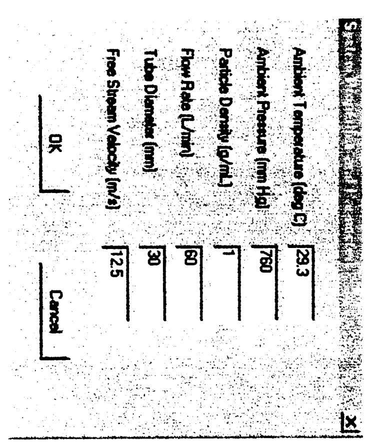

Figure 2: The "System Properties and Parameters" dialog.

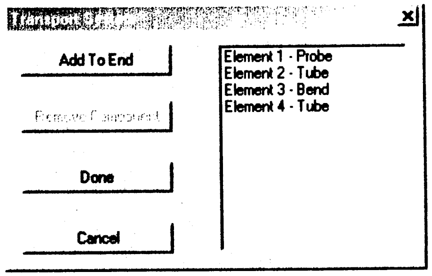

Figure 3: The "Transport System" dialog of the "Setup" menu.

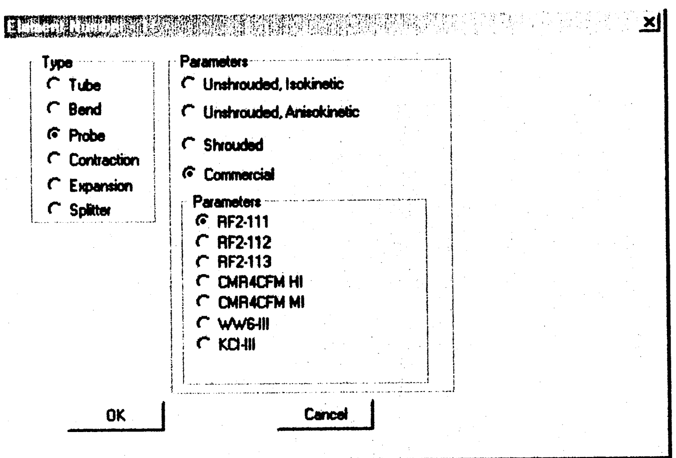

Figure 4: The "Element Number" dialog box. When "Probe" is selected a list of probe types is presented, and when "Commercial" is selected, a list of the commercially-available probes is shown.

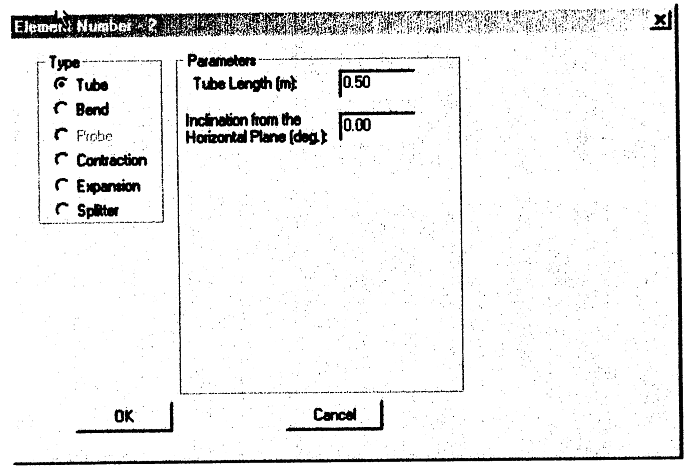

Figure 5: The "Element Number" dialog box with "Tube" selected.

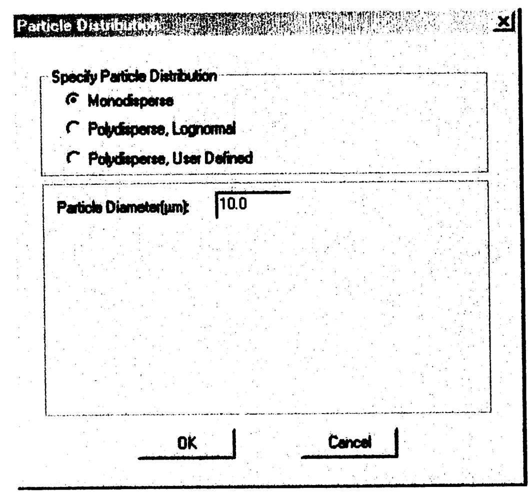

Figure 6: The "Particle Size Distribution" dialog box with "Monodisperse" and "10" µm selected.

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TOTAL PENETRATION

Total Penetration:      87.2%
#           Component              Penetration
1           Commercial Probe        97.9%
2           Tube                    94.8%
3           Bend                    98.8%
4           Tube                    96.0%
Stokes Number:          0.0140
Reynolds Number:          2641


NOTES:


<< Calculations were made with the best possible >>
<< extrapolations of the model(s).               >>
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Figure 7: The "Total Penetration" mode of the "Analysis" menu.

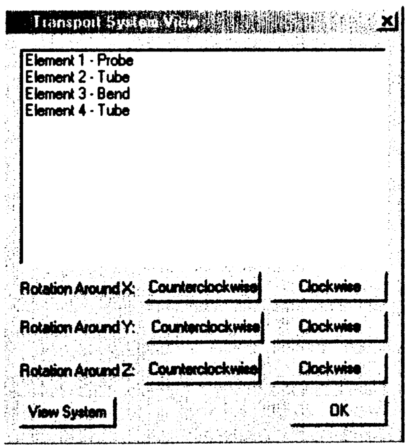

Figure 8: The "Transport System View" dialog box from the "View" menu. The "View System" button will provide a 3-D picture of the transport system.

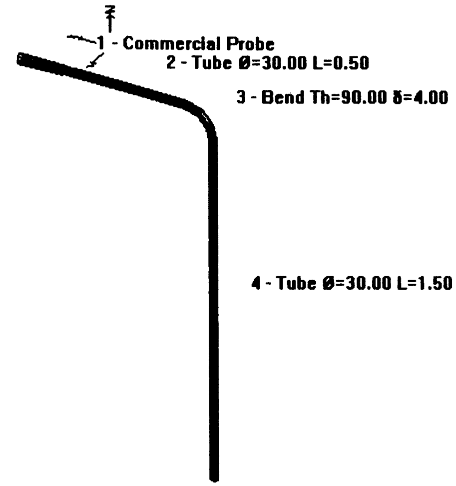

Figure 9: Pictorial representation of the example aerosol sampling system generated from use of the "Transport System View" dialog.

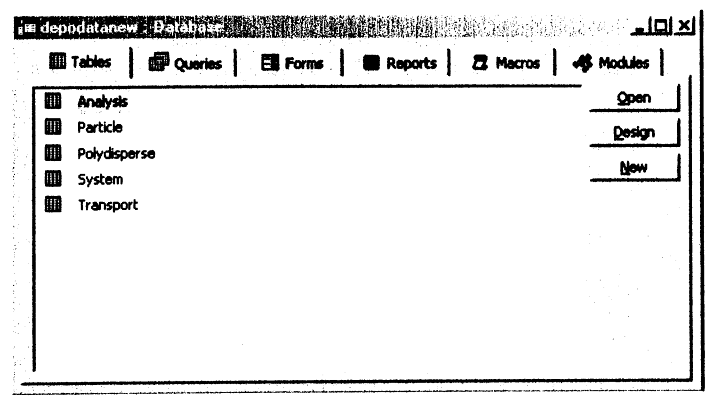

Figure 10: Dialog box in Microsoft Access for a saved file.